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ABSTRACT

This paper discusses the potential of Spacelab in a future STS extension programme, covering orbital service module, Spacelab and space station-related applications.

A brief review of projected user needs is presented identifying in particular the near term need for increased electrical power, energy and prolonged flight durations. With a view to these needs, the extention potential of the power, thermal control, structure, data handling and life support designs of Spacelab are discussed. The ESA proposal for a three-step evolutionary programme of Spacelab is described, which leads from the present Orbiter fixed sortie mission applications to a long duration free-flying capability.

From the extension study work carried out so far, it is concluded that Spacelab, particularly due to its modular design, provides inherent growth potential which lends itself to a cost effective exploitation in a future evolutionary space programme.

1. INTRODUCTION

The current Space Shuttle System is being developed to ". . . help transform the space frontier of the 1970s into familiar territory, easily accessible for human endeavour in the 1980s and 1990s.*

To achieve this ambitious goal, the Shuttle System has certain features such as reusability, short turn-around times, relaxed constraints for users, manned attendance and decreased transportation cost which will enable more economical exploitation of space than possible to date with expendable launcher systems.

Spacelab as a highly integrated element of the Space Shuttle System is designed to capitalise on above economical principles for the benefit of the users.

Being conceived as a multidisciplinary laboratory and observatory facility which converts the basic resources of the Shuttle Orbiter into laboratory type of user support, Spacelab exhibits cost effective design provisions such as:

- reusability of Spacelab elements for 10 years
- short turn-around times
- laboratory reconfiguration flexibility for mission optimisation due to modular concept (see Figure 1)
- man-tended or autocontrolled experimentation
- standardised user interfaces
- real time involvement of users on the ground
- more benign launch environments than rockets
- reduced need for highly reliable experiment designs compared to those for satellites

The current design of Spacelab is fully responsive to the original technical requirements established jointly between the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) in 1973. These requirements specified that Spacelab depending on the Orbiter services for power, heat rejection, communications, and orbit and attitude control, must remain in the cargo bay of the Orbiter during a mission of nominally seven days, extendable up to 30 days.

However, as a result of the knowledge gained during the developments of both, the Shuttle and Spacelab, and as a consequence of refined definitions of user requirements, several desirable improvements of the present Shuttle/Spacelab system have been identified.

It was recognised that, in particular for the near future, the limited power, energy and heat rejection capabilities as well as the limited mission duration are prime candidates for improvement. Both, NASA and ESA, are studying these improvements in detail. In particular, the NASA proposal to complement the Space Shuttle System by a free-flying power- or service module may encourage the development of a variety of Spacelab-derived elements with free-flying capabilities.

*(President R. Nixon)

In the following, the development prospects of Spacelab for the future are discussed and the ESA proposal for an evolutionary Spacelab programme, as submitted for approval to the governing authorities of ESA is described.

2. EVOLVING USER NEEDS

Through its coordinating organisation the "Joint User Requirements Group" (JURG), NASA and ESA have examined the most desirable extensions of Spacelab capabilities for the near-, medium- and far future, as listed in Figure 2.

For the near future, the highest priority candidates for capabilities extensions are:

- increased electrical power and heat rejection for payloads
- mission duration extension beyond seven days
- increased flexibility in payload service utilisation

The increase in electrical power and concurrently in heat rejection capability, in particular for space processing and space physics missions, is required to achieve a better balance between physical accommodation capabilities (e.g., mass and volume provisions) and experiment resources. Present power and heat rejection limitations prevent the simultaneous operation of several medium power demanding experiments. A power supply of four to five KW to payloads will require an increase of two to three KW for the most critical Spacelab configurations (e.g., module/pallet configurations).

The need for mission duration extension is also supported by the majority of Spacelab users.

Extended missions will lead to improve mission cost effectiveness, since considerably more results are obtainable for relatively little extra operations cost in comparison to the launch cost.

In particular for astronomical missions the scientific return is nearly proportional to mission duration. Some disciplines have specific requirements for prolonged missions, e.g., certain crystal growth processes (material science) require about two weeks of continuous operation, and studies of cardio-vascular or metabolic problems (life science) require up to four weeks of observation time.

Requirements for more operational flexibility are aiming at increased access capabilities to standard Spacelab services, e.g., more power outlets, increased computer memory, short pallets, small pointing systems.

For the medium and long term future, there is a definite demand for even more electrical power (up to 40 KW for 1988-1990) and practically unlimited orbital staytime for nearly all disciplines. There is also a very determined trend to free-flying Spacelab elements, particularly for pallets, in order to minimize man-motion and Shuttle environmental effects on mission performance.

3. NEWLY REQUIRED SPACELAB CAPABILITIES AND PROPOSED PROGRAMME EVOLUTION

Above discussed increases in user demands will either necessitate adaptations to or extensions of the present Spacelab system, or will require costly new developments.

Earlier studies in the US (Reference 1) and Europe (Reference 2) have shown that Spacelab offers inherent design flexibility which lends itself for cost effective adaptations to future mission needs.

To utilise the hardware production capabilities most economically as well as the technological know-how and the operational experience to be gained from the first Spacelab flights, ESA has proposed a phased Spacelab development programme (Reference 3). This programme recommends a sequence of discrete development steps and options divided into three major increments, namely the "Initial Step," the "Medium Term" and the "Far Term" alternatives as shown in Figure 3.

The Initial Step relies on the provision of increased power from an Orbiter augmented by a solar array, and emphasizes the need for increased electrical power and heat rejection capabilities to experiments as well as increased operational flexibility of resources utilization and prolonged stay-times on orbit.

The medium and long term evolution aims at increasing the autonomy of Spacelab in Shuttle tended or autonomous free-flying modes and the provisioning of dedicated modules and pallets which could serve as building elements for future space stations or service platforms.

Figure 4 summarizes the major candidates for Spacelab capability extensions.

4. PROPOSED IMPROVEMENTS FOR THE INITIAL STEP

In response to priority requirements of the users and the NASA plans to augment the Shuttle electrical power generation capabilities for prolonged flights, ESA has performed a number of industrial studies (References 4 to 9) to substantiate the feasibility of cost effective SL improvements in the desired areas.

The results of these studies have been presented to the ESA Member States (Reference 10) in order to obtain by mid 1979 authorisation to proceed with the implementation of the selected improvements, which comprise:

a) All modifications to Spacelab necessary to enable extended missions durations up to 30 days by

   - provision of additional nitrogene storage (Figure 5)
   - storage provisions for additional cartridges for carbon dioxide removal

– additional of an active igloo pressure control system
– inflight exchange capability of critical equipment to maintain a high mission success probability

b) All modifications to Spacelab which make it compatible with an Orbiter that provides four KW additional electrical power to experiments by

   – addition of a Spacelab radiator to allow compatible heat rejection capabilities (Figure 6)
   – increase of Spacelab water flow rate to facilitate higher heat transportation
   – modification to the Spacelab power feeder to allow for peak power capabilities of up to 18 KW

c) Selected modifications and additions to Spacelab to increase its operational flexibility by

   – providing low power modes
   – extension of the computer memory and simplification of data bus interface units
   – providing shorter pallets and pallet support structures (Figure 7)
   – providing small pointing mounts
   – increasing the number of cold plates on the pallets and adding an experiment heat exchanger

Many other options which were initially considered desirable improvements, such as coupling of all computers, addition of disk memories, are not being recommended because of prohibitive costs and also for operational considerations for decentralised concepts as discussed in chapter 5.3.

5. SPACELAB GROWTH POTENTIAL FOR FUTURE APPLICATIONS

As mentioned above, future Space Shuttle supported systems will develop towards long orbital stay times with autonomous service capabilities to the users.

It is foreseeable that for dedicated commercial applications such systems will tend to be highly integrated and tailored to the particular needs of the user.

For research and technology development oriented space facilities, however, a higher degree of flexibility and growth potential for on-orbit reconfiguration and extension is desirable to satisfy a variety of mission objectives. Designs responsive to those requirements will therefore attempt to minimize physical and operational interfaces. To avoid complex facility integration processes on the ground and in orbit, it is therefore expected that, in particular for unmanned space platforms, the services of the central facility will most likely be restricted to power provisioning, attitude control, communication transfer and structural support. For data handling and processing functions, and possibly also for heat rejection, there will be trend towards decentralisation. Aspects of man-safety, high probability of mission success, on-orbit maintainability, repair, will be important considerations for all future systems with long stay times in space.

In the following a short, subsystem by subsystem discussion, describes the evolutionary potential of the current Spacelab design in expectation of future mission requirements.

5.1 Electrical Power Distribution

The present design of the Spacelab electrical power distribution system (EPDS) is designed to handle eight to 12 KW of power depending on the selected SL configuration. Presently, this potential is only used for short duration peaks because of the limited power and heat rejection capabilities from the Orbiter.

The full capability of Spacelab could be utilised if the Orbiter power augmentation and a Spacelab radiator would become available. With only minor modifications at the Spacelab power feeder the power distribution capability can be increased to 15 KW.

Very high power levels (20 to 30 KW) would require significant modifications of the present conditioning and distribution system.

5.2 Thermal Control

Increased electrical power supply requires a corresponding heat rejection capability. Present near term plans foresee, therefore, for the most critical module configurations, a radiator which would allow up to four KW additional heat rejection.

A modular design adaptable to all module or pallet configurations in Orbiter attached or free-flying modes is under investigation.

Heat loads in the module or pallet liquid loops beyond approximately 13.5 KW will require redesign of pumps and other elements to allow for higher flow rates.

Analysis has shown that the lifetime of the multi-layer insulation subjected to cyclic thermal loads meteoroid puncture and degradation of thermo-optical performance due to ultraviolet radiation poses no problem for 30 day mission. However, for longer missions this area requires further assessment.

Also, the radiation and micrometeoroid protection system must be redesigned and methods for on-orbit maintenance and repair have to be developed for long durations missions.

5.3 Improved Data Handling Capabilities

The Command and Data Management Subsystem (CDMS) as currently developed provides for a centralized multiprocessor system. As a near-term objective it is intended to introduce more capabilities into the current system by enlarging the core storage capability of the computers.

Rapidly advancing technology in the field of microprocessors and LSI memories is being adopted more and more by users. This will eventually lead to a decentralised data management system whereby the current central computing system will work together with the many preprocessors located in the experiments (Figure 8).

The operational role of the current system will therefore change in the future to more general task management, such as information retrieval, report generation, program storage, operations coordination and interactive man/machine interfaces. Specific tasks also currently carried out by the experiment-dedicated computer, such as data collection and processing, fast control loop calculations for experiments and self-test and checkout routines may in the future be left to a large extent to the specific users provided microprocessors.

A similar development may occur in the software area, specifically in the field of conversational language capabilities. For the user the benefit of this development would result in

- a better standardization of the operational interfaces with the Spacelab CDMS;
- experimenter-determined processing rates within an experiment largely independent from Spacelab control;
- easier Spacelab preintegration activities through more autonomy within the experiment itself;
- improved conversational capabilities via Spacelab CDMS consoles.

5.4 Life Support

The environmental control and life support subsystem (ECLS) of the current Spacelab provides for control of air composition (N_2/O_2) and pressure, temperature, humidity and carbon dioxide (O_2) concentration. Extensions from the present seven-day to 30-day capability will only require additional N_2 storage and additional LIOH cartridges for CO_2 removal.

Longer mission durations, in particular free-flights, will, however, require extensive additions to the present system, such as storage of nitrogen and oxygen in cryogenic form and active control of atmospheric contamination.

5.5 Crew Habitability

In its present configuration, Spacelab is conceived as a work facility only, while sleeping, personal hygiene and food provisions are contained in the Space Shuttle.

A number of concepts exist to add sleeping provisions to the present layout of Spacelab (see Figure 9) in order to increase crew comfort during prolonged spaceflights.

Complex space-based facilities of the future will require the presence of man for assembly, control, maintenance and repair functions. This will require a permantly or semi-permanently manned module.

Spacelab with its shirt sleeve environment, its applied design principles for crew accommodation, and its inherent flexibility for interior reconfiguration exhibits most promising capabilities to serve as a "Crew Habitation Module" for a space platform. Figure 10 shows a crew habitation module concept under study at ERNO (Reference 11).

5.6 The Structural Elements of Spacelab

ESA and NASA studies (Reference 12) indicate that the structural parts of Spacelab have a very high potential of being modified into a variety of multipurpose or dedicated modules and pallets either attached to the Shuttle or as free-flying elements. In configuration and size, it can be assumed that most future modules will resemble Spacelab because the dimensions are limited by the cargo bay of the Space Shuttle which will be used for some time to come as the primary transport vehicle to space.

It is also believed that the availability of the necessary manufacturing tools and of skilled personnel will enable future Spacelab structural elements to be manufactured more economically than new developments.

5.6.1 The Module Structure

For the present, long module configuration analyses of ERNO have shown that mission durations of up to one year appear feasible with respect to meteoroid resistance. For longer mission durations, redesign of the meteoroid protection system is required and Aeritalia is planning to evaluate an intergrated thermal and meteoroid protection system for very long spaceflight durations.

Radiation analyses, also performed by ERNO and based on NASA-defined allowable radiation doses, indicate that operations for 90 days and orbit altitudes of up to 700 KM are feasible without additional shielding. However, should living/sleeping quarters be required in the module, additional local shielding could easily be introduced.

Air leakage through the seals present no serious problem for prolonged flights. If, however, extremely long mission durations cause aging of the sealant, improved designs could be developed with improved protection and redundant safety features. For space platform applications, most of the seals could be deleted by welding module elements together.

Another structural area which has to be studied in detail, in particular for very long missions, is crack forming and propagation resulting from extended pressurization periods in combination with thermal cycling fatigue caused by alternating sun/deep space exposure.

The structural behaviour of the module shell comprizing three and four segments must be studied. The main area of concern is the inertia loading of the shell due to the higher mass of the module. Strength analyses must also be performed to verify the docking capability. However, should these analyses require local reinforcements of the module, they can be incorporated without changing the basic design concept by modifying the software for the numerically controlled machines accordingly.

In regard to configurational adaptability, the Spacelab module offers considerable flexibility for interior layouts and sizes both for Orbiter-attached modes and free-flight applications.

Figure 11 presents an artist concept of a module configured as a life science laboratory.

With the development of futher interconnected structures, the Spacelab modules can be used in a variety of cluster arrangements. (Figure 12).

Figure 13 shows a space station concept employing Spacelab structures.

5.6.2 The Pallet Structure

Like the Spacelab module, the pallet has inherent capabilities to adapt to future mission needs. To provide more flexibility for smaller payloads BAe has studied the possiblity of pallet derivatives down to one pallet frame with the result that a half pallet (1.5 m long) seems to offer the best compromise for users. Other studies (Reference 12) are concentrating on auxiliary pallet support structures and supplementary new bridge structures which may offer better field of view conditions to small experiments as shown in Figure 14.

For automated payloads requiring longer mission durations and/or higher power levels than provided in the Orbiter attached mode, the free-flying pallet in combination with a service module is of interest. Typical candidates for such missions are space processing payloads, advanced Earth observation and atmospheric physics clusters and solar/astronomy packages.

Figure 15 presents one of the space platform concepts under investigation at NASA, employing Spacelab pallets as exchangeable instrument carriers. Depending on the services offered by a central service platform facility, some new services (e.g., limited data handling and heat rejection capabilities) will have to be provided on the pallets.

The final step could be a fully autonomous free-flying pallet providing standard subsystem supports for a variety of observational experiments which could not tolerate disturbances due to dynamic effects of large space platform structures. Particular for large telescopes, the present pallet structure which "wraps" around the instrument would be a cost effective solution as an alternative for satellite-type structures (Figure 16).

6. CONCLUSION

Based on projected user requirements, an extension of the STS/Spacelab system is being planned by NASA and ESA. The proposed evolutionary Spacelab development foresees for the near future increased power, heat rejection and operational flexibility of the current Spacelab design.

Spacelab derivatives of the module, the pallet, and their subsystems are potential candidates as elements for future free-flight and space platform applications, for which aspects of crew safety, mission success probability, mission reconfiguration capability, serviceability, maintainability, repairability and low cost operation will be of primary importance.

Continued close cooperation of NASA and ESA is required to arrive at cost optimised design solutions and to synchronise development planning for STS/Spacelab systems extensions.

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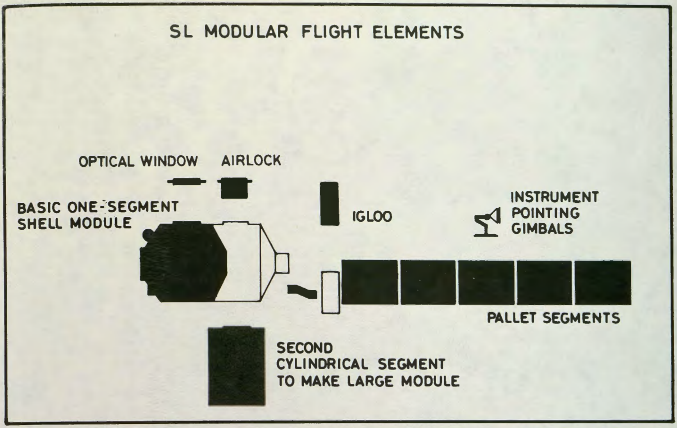


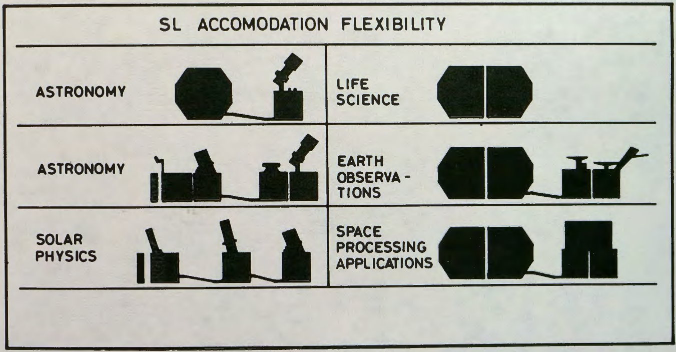


Figure 1. Spacelab Modular Design and Reconfiguration Flexibility

DISCIPLINE	OBJECTIVES / TYPICAL SPACELAB CANDIDATES	DESIRED NEAR-TERM SPACELAB IMPROVEMENTS	FUTURE TRENDS
LIFE SCIENCES	- Animal Holding Units - Centrifuges - SLED - Multi-User Bioracks	- Longer mission duration (2-3 weeks) - Higher ascent/descent power (1.5 kW) - Higher on-orbit power (4-5 kW) - Several TV channels	- Considerable increase in mission duration - Largest crew possible - Possibly dedicated Spacelab module
MATERIAL SCIENCES	- Multi-user facilities with several furnaces - Electrophoresis facility - Fluid physics facility	- Low g-levels ($< 10^{-4}$g) - High continuous power: 4-8 kW - Emphasis on water cooling in module	- Growth in power demand - Solar-powered furnaces - Candidate for Power Module/ SL free flyer
ATMOSPHERIC PHYSICS/ GEODESY/ MAGNETOSPHERIC & PLASMA PHYSICS	- Many small experiments (e.g. passive atmospheric sounder) - LIDAR - He-cooled IR telescope - Active perturbation experiments	- 1-2 weeks for initial tests - 4-5 kW power - Cryogenic cooling - Several small pointing mounts - Long booms; subsatellite	- Many flight opportunities requested - Candidate for Power Module/ SL pallet
SOLAR PHYSICS / ASTRONOMY	Several small and medium-size telescopes/facilities, e.g.: - EXSPOS (X-ray) - LIRTS (infrared) - Double-Compton (γ-ray) - GRIST (solar X-ray)	- Scientific gain nearly proportional to observation time - Simultaneous operation of several pointing mounts - Real-time monitoring of experiment data on ground	- Advances in detectors with increased spatial/time resolution - Trade off: captive/free-flying mission mode
EARTH OBSERVATION	Development / tests in remote sensing - Metric camera - Passive / active microwave facility - Multi-spectral scanners	- 2-3 weeks mission duration - 4-5 kW power - High data rate storage / transmission	- Higher data rates: 100-200 Mbps - In-orbit antenna storage - Increase in power demand
SPACE TECHNOLOGY / COMMUNICATION - NAVIGATION	Development / test of space systems, e.g. - Heat pipes - Tribology - Cryostat - Synchronisation of atomic clocks	No driver discipline, only partial payloads	- Demonstration of assembly / construction of large structures (antennas, solar arrays)

Figure 2. Projections of Desired Spacelab Improvements

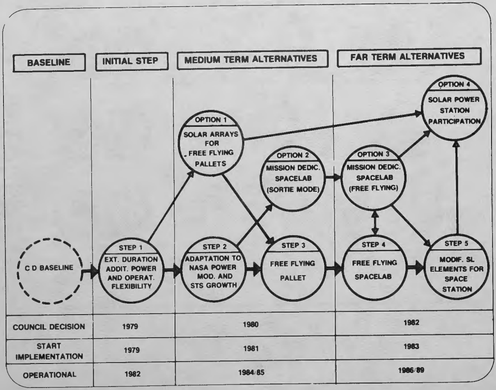


Figure 3. Spacelab Follow-On Development Approach

NEAR TERM IMPROVEMENTS (UP TO 1983)	MEDIUM TERM IMPROVEMENTS (UP TO 1985)	FAR TERM IMPROVEMENTS (BEYOND 1986)
BASELINE SPACELAB WITH : • INCREASED CDMS CAPABILITY • ON-ORBIT EXCHANGE OF SPARES • INCREASED POWER PROVISIONING • ACTIVE IGLOO REPRESSURISATION • INCREASED COOLING PROVISIONS • SMALL PALLETS AND PALLET SUPPORT STRUCTURES • DEDICATED LABORATORY LAYOUTS	• INCREASED POWER ROUTING • 3 OR 4 SEGMENTS MODULE • INCREASED CREW SAFETY AND COMFORT PROVISIONS • IMPROVED METEOROID/ RADIATIONS SHIELDING • INCREASED STOWAGE PROVISIONS • IMPROVED TRACE CONTAMINANT CONTROL SYSTEM (MOLECULAR SIEVE) • INCORPORATION OF PREVIOUS ORBITER FUNCTIONS FOR : - COMMUNICATION - MISSION/VEHICLE CONTROL • ON-ORBIT DEPLOYMENT/RETRIEVAL PROVISIONS • DOCKING PROVISIONS FOR POWER MODULE • DEDICATED SL LAYOUTS	DEDICATED FREE-FLIGHT SPACELABS FOR VARIOUS FUNCTIONS, E.G. • CREW HABITATION • SUBSYSTEM SERVICES • CARGO STORAGE & LOGISTICS • TRANSFER OR DOCKING • SAFETY AND ESCAPE • MISSION APPLICATIONS • CONSTRUCTION ETC...

Figure 4. Major Spacelab Improvement Candidates

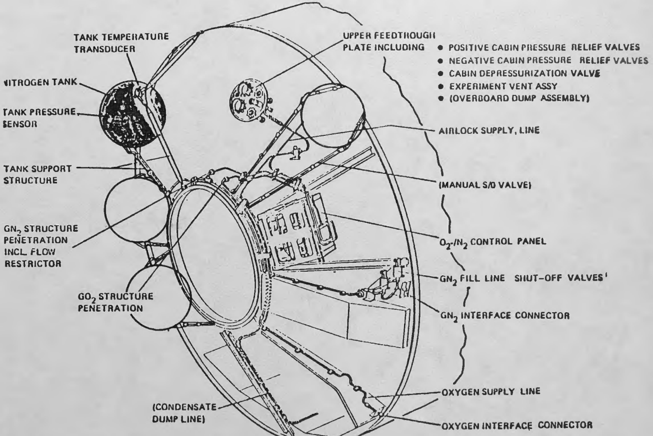


Figure 5. Additional Nitrogen Tanks Mounted on Forward End-Cone of Spacelab

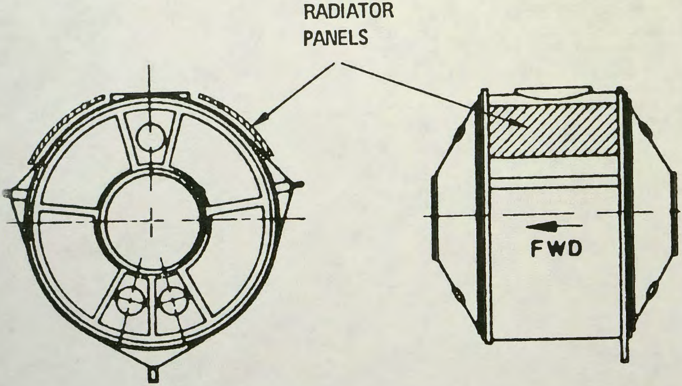


Figure 6. Short Module with Radiator Panel Segments

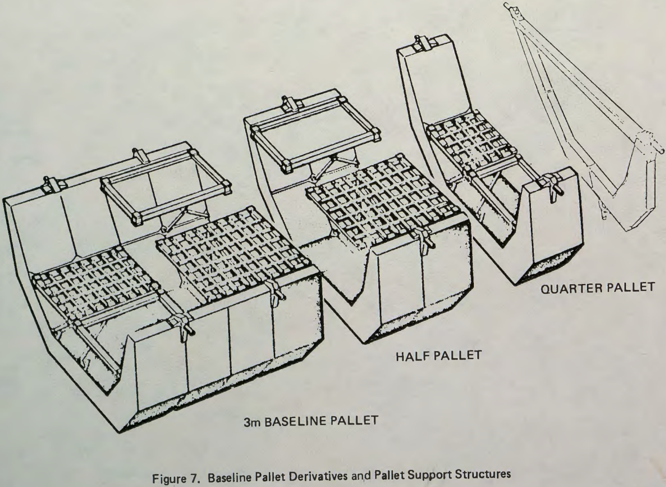
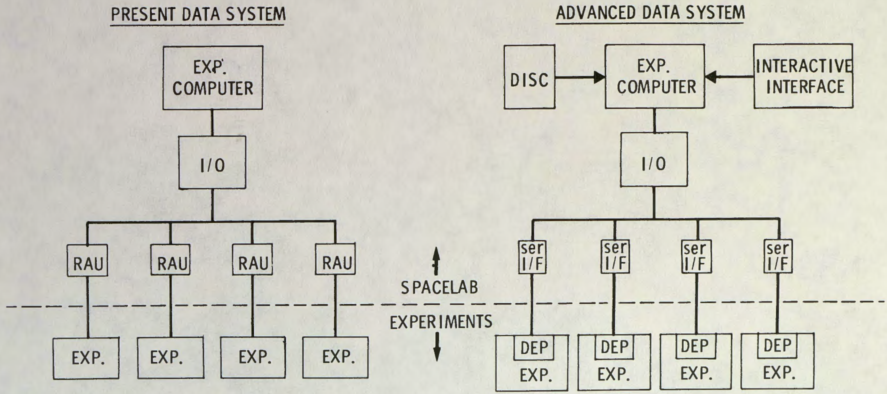


Figure 7. Baseline Pallet Derivatives and Pallet Support Structures



- Centralized data processing

- Central computer for monitor and control
- Data processing in Dedicated Experiment Processors (DEP)
- Improved central peripherals, fast memory, interactive man/machine interface
- Simplified serial interface (mini RAU) for DEP

Figure 8. Trends for Advanced Command and Data Management on Spacelab

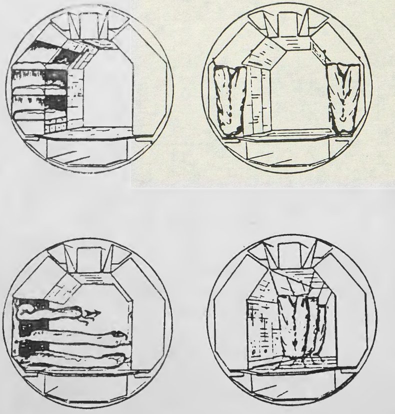


Figure 9. ERNO Concepts for Crew Accommodation in SL Module
for Prolonged Space Flights

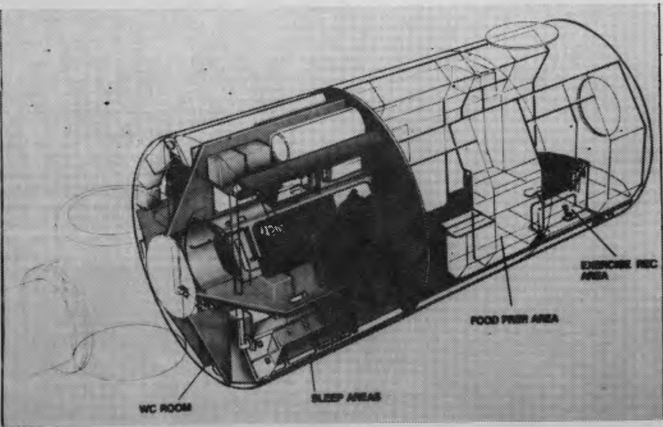


Figure 10. Crew Habitation Module

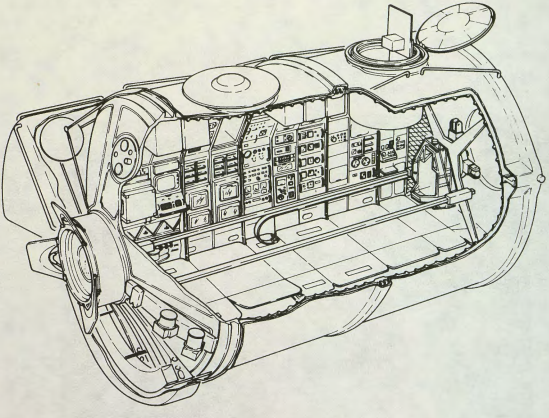


Figure 11. Artist Concept of a Spacelab Module Configured as a Dedicated Life Laboratory

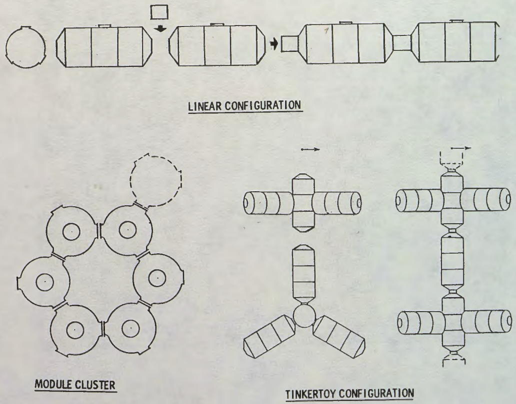


Figure 12. Possible Arrangements for Module Clusters

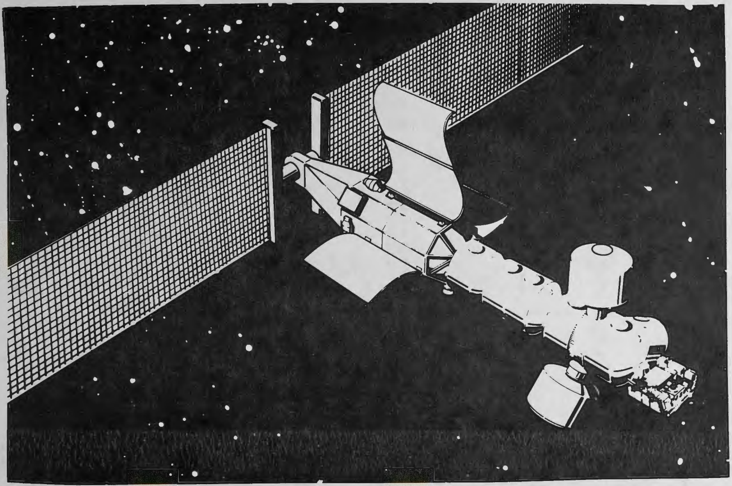


Figure 13. Space Station Concept Employing Spacelab Structures

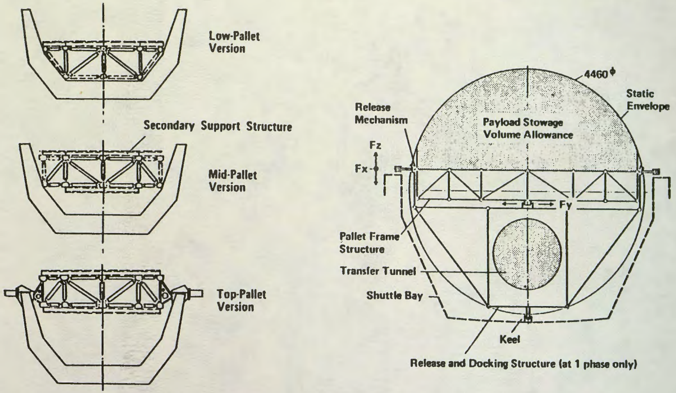


Figure 14. Pallet Support Structures and Supplementary New Bridge Structures

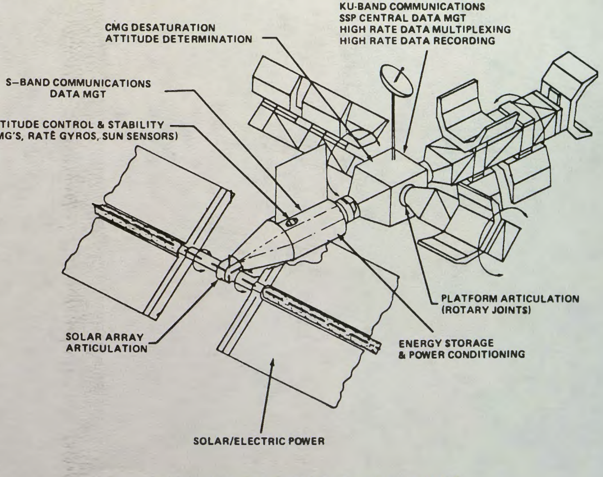


Figure 15. Space Platform Concept Under Investigation at NASA

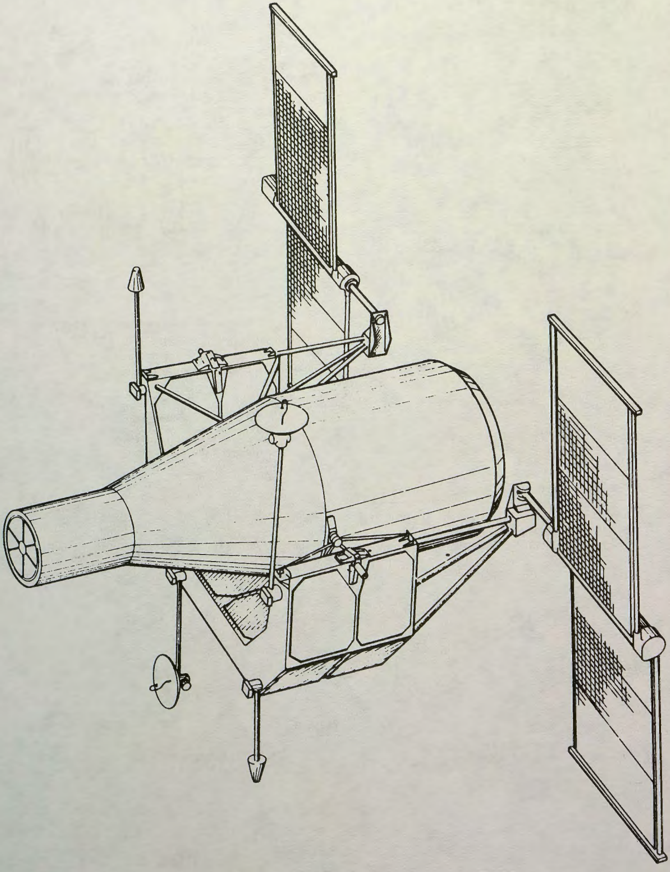


Figure 16. Concepts or Full Autonomous Flying Pallets